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Invention: PERPENDICULAR MAGNETIC RECORDING MEDIUM, MANUFACTURING METHOD THEREOF, AND MAGNETIC RECORDING-REPRODUCING APPARATUS

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SPECIFICATION

TITLE OF THE INVENTION

PERPENDICULAR MAGNETIC RECORDING MEDIUM, MANUFACTURING METHOD THEREOF, AND MAGNETIC RECORDING-REPRODUCING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2002-345994, filed November 28, 2002, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1.   Field of the Invention

The present invention relates to a magnetic recording-reproducing apparatus used as a hard disk apparatus, particularly, to a magnetic recording-reproducing apparatus utilizing the magnetization in the perpendicular direction, a perpendicular magnetic recording medium used therein, and a method of manufacturing the same.

2.   Description of the Related Art

One of the typical magnetic layers used in a perpendicular magnetic recording medium is, for example, a CoCr series magnetic layer. In the CoCr series magnetic layer, Cr in an amount larger than, for example, 20 atomic percent is added to Co so as to permit nonmagnetic Cr atoms to be segregated around the Co series magnetic crystal grains. As a result,

the magnetic interaction produced among the magnetic crystal grains is separated so as to achieve a magnetic recording of high recording density.

In recent years, the perpendicular magnetic recording medium is required to exhibit further improved recording density. However, if the size of the magnetic crystal grains contained in the perpendicular recording layer is made smaller for improving the medium SN ratio (SNRm), the thermal decay tends to be generated, which give rise to the problem that the recorded information tends to be erased.

Such being the situation, various studies have been made for improving the recording-reproduction characteristics while maintaining the resistance to the thermal decay by adding various elements to the Co series perpendicular magnetic recording layer. For example, it is proposed in Japanese Patent Disclosure (Kokai) No. 11-185236 that at least one element selected from the group consisting of Cr, Fe, Mo, V, Ta, Pt, Si, B, Ir, W, Hf, Nb, Ru, Ni and a rare earth element should be added to a base material containing Co as a main component. However, it was difficult to improve the SNRm and prevent the thermal decay at the same time.

On the other hand, Japanese Patent Disclosure No. 63-148411 discloses a magnetic recording medium comprising a longitudinal magnetic layer. It is

taught that the longitudinal magnetic layer is formed by forming a magnetic layer prepared by adding Ta, Mo, and W to a CoCr system on an underlayer consisting of Cr.

5   However, even if the longitudinal magnetic layer is applied to a perpendicular magnetic recording medium, Mo or W disturbs the crystal orienting properties so as to markedly impair the perpendicular magnetic anisotropy, with the result that any of the

10   SNRm and the capability of preventing the thermal decay were not improved. As pointed out above, the longitudinal magnetic recording medium and the perpendicular magnetic recording medium differ from each other in various aspects including, for example,

15   the compositions of the underlayer and the magnetic layer, the direction of the magnetic anisotropy, and the use or nonuse of the soft magnetic backing layer depending on the difference in the magnetic head. It follows that it is impossible to obtain a satisfac-

20   tory effect even if the magnetic layer used in a longitudinal magnetic recording medium is simply applied to the perpendicular magnetic recording medium.

BRIEF SUMMARY OF THE INVENTION

25   According to one of embodiments of the present invention, there is provided a method of manufacturing a perpendicular magnetic recording medium, comprising

forming on a nonmagnetic substrate a magnetic layer
at 280 to 450℃ by using a magnetic layer-forming
material containing at least one additive component
selected from the group consisting of cobalt,
platinum, molybdenum and tungsten, the magnetic layer
being constructed to include a plurality of magnetic
crystal grains separated from each other by crystal
grain boundaries and providing a perpendicular
magnetic layer in which the additive component is
segregated in the crystal grain boundaries.

According to one of embodiments of the present
invention, there is provided a perpendicular magnetic
recording medium, comprising a nonmagnetic substrate;
and a perpendicular magnetic layer containing at least
one additive component selected from the group
consisting of Co, Pt, Mo and W, formed at 280 to 450℃
on the nonmagnetic substrate, and constructed to
include a plurality of magnetic crystal grains
separated from each other by crystal grain boundaries,
the additive component being segregated in the crystal
grain boundaries in the perpendicular magnetic layer.

Further, according to one of embodiments of the
present invention, there is provided a magnetic
recording-reproducing apparatus, comprising the
perpendicular magnetic recording medium defined above;
a mechanism for supporting and rotating the perpen-
dicular magnetic recording medium; a magnetic head

including an element for recording information in the perpendicular magnetic recording medium and another element for reproducing the recorded information; and a carriage assembly supporting the magnetic head such

5   that the magnetic head is movable relative to the perpendicular magnetic recording medium.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification,

10   illustrate embodiments of the present invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the present invention.

15   FIG. 1 is a graph showing the relationship between the film-forming temperature and the SNRm in respect of a CoPtCrMo perpendicular magnetic layer;

FIG. 2 is a graph showing the relationship between the film-forming temperature and the SNRm in

20   respect of a CoPtCrW perpendicular magnetic layer;

FIG. 3 is a graph showing the relationship between the film-forming temperature and the SNRm in respect of a CoPtCrMoW perpendicular magnetic layer;

FIG. 4 is a graph showing the relationship

25   between the Cr content and the SNRm in respect of a CoPtCrMo perpendicular magnetic layer;

FIG. 5 is a graph showing the relationship

between the Mo content and the SNRm in respect of a CoPtCrMo perpendicular magnetic layer;

FIG. 6 is a graph showing the relationship between the Mo content and the SNRm in respect of a CoPtCrMoW perpendicular magnetic layer;

FIG. 7 is a cross sectional view showing as an example the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 8 is a cross sectional view showing as an example the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 9 is a cross sectional view showing as an embodiment the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 10 is a cross sectional view showing as another embodiment the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 11 is a cross sectional view showing as another embodiment the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 12 is a cross sectional view showing as another embodiment the construction of a perpendicular magnetic recording medium according to the present invention;

FIG. 13 is a cross sectional view showing as another embodiment the construction of a perpendicular magnetic recording medium according to the present invention; and

5 FIG. 14 is a cross sectional view showing as still another embodiment the construction of a perpendicular magnetic recording medium according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

10 The method of the present invention for manufacturing a perpendicular magnetic recording medium comprises forming a perpendicular recording layer on a nonmagnetic substrate. In forming the perpendicular magnetic recording layer, a magnetic

15 layer is formed at 280 to 450°C by using a magnetic layer-forming material containing at least one additive component selected from the group consisting of Co, Pt, Mo and W, thereby forming a perpendicular magnetic layer constructed to include a plurality of

20 magnetic crystal grains separated from each other by crystal grain boundaries and having the additive component segregated in the crystal grain boundaries.

Also, the perpendicular magnetic recording medium of the present invention, which can be manufactured

25 by the method described above, is a perpendicular magnetic recording medium comprising a nonmagnetic substrate and perpendicular magnetic layer formed on

the nonmagnetic substrate. The perpendicular magnetic layer contains Co and Pt and at least one additive component of Mo and W. The perpendicular magnetic layer, which is formed at the temperature within

5   a range of between 280℃ and 450℃, is constructed to include a plurality of magnetic crystal grains separated from each other by crystal boundaries. The additive components are segregated in the crystal grain boundaries.

10   According to one embodiment of the present invention, Mo and W are sufficiently diffused so as to be segregated at the crystal grain boundaries, with the result that the effect of magnetically separating the magnetic crystal grains is improved so as to

15   obtain a high SNRm value and an excellent resistance to the thermal decay.

It is possible to add further Cr to the perpen-dicular magnetic layer used in the present invention.

Among the additive components of Mo, W and Cr, W

20   produces the highest effect of magnetically separating the magnetic crystal grains. Mo produces an intermediate effect and Cr produces the lowest effect of magnetically separating the magnetic crystal grains. The dependence of effects is caused by

25   difference in lattice constants and in structures of crystal. W has the largest lattice constant, Mo has the intermediate lattice constant, and Cr has the

smallest lattice constant. The Co-Cr bond assumes
the same hexagonal close-packed structure within the
magnetic crystal grain and at the segregated crystal
boundary, on the other hand, each of the Co-Mo bond
and the Co-W bond assumes the structure, e.g., a CsCl
type structure, at the crystal boundary after the
segregation, which differs from the structure assumed
within the magnetic crystal grain.

However, the diffusion rate (segregation rate)
each of Mo and W is lower than that of Cr, and the
particular rate of W is lower than that of Mo. Such
being the situation, Mo and W are unlikely to be
diffused into the crystal boundary. The difference
in the diffusion rate noted above is caused by the
difference in the melting point among these additive
components. Specifically, Mo has a high melting point
of about 2,700°C, and W also has a high melting point
of about 3,500°C. On the other hand, the melting
point of Cr is low, i.e., about 1,700°C. What should
also be noted is that, where Mo and W are left within
the Co-based magnetic crystal grain, the crystal
orienting properties and the magnetic anisotropy of
the magnetic crystal grain tend to be markedly
disturbed because Mo and W have larger lattice
constants than that of Co.

As described above, Mo and W, which are expected
to produce a high magnetic separating effect, give

rise to problems when put into practical use.

Incidentally, in the case of using Pt, the distance between the crystal lattices in the perpendicular recording layer tends to be increased so as to lessen the disturbance in the crystal orienting properties that is brought about by Mo and W, thereby improving the segregation thereof.

Under the circumstances, the present inventions have attained a perpendicular recording layer in an attempt to permit Mo and W to be segregated at the crystal boundary in larger amounts. Specifically, the perpendicular magnetic layer was formed by changing the film-forming temperature under the conditions that Pt was added to the recording layer, and a substance having a high resistance to heat was heated to a sufficiently high temperature.

FIG. 1 is a graph showing the relationship between the film-forming temperature and the SNRm in respect of a perpendicular recording layer of Co-16 at%Pt-14 at%Cr-xat%Mo. Curve 101 included in the graph covers the case where x is 0, curve 102 included in the graph covers the case where x is 5, and curve 103 included in the graph covers the case where x is 10.

As apparent from curve 101, where Cr is added as a segregating component to the CoPt series magnetic material, the optimum SNRm was obtained at about 250°C

because Cr exhibits a relatively high segregating

rate. On the other hand, when it comes to the

perpendicular magnetic recording medium including

a perpendicular recording layer containing Cr or Mo,

5   a maximal value derived from Mo was caused to appear

at about 350℃ in addition to the maximal value

derived from Cr, which appeared at about 250℃, as

apparent from curves 102 and 103. It is considered

reasonable to understand that the particular

10   phenomenon was brought about by the situation that

each of Mo and Cr has a low segregating rate and has

a high melting point. Curves 102 and 103 support

that, in the case of using a perpendicular recording

layer containing Co, Pt, Cr and Mo and not containing

15   W, a satisfactory SNRm value can be obtained at 280 to

450℃, desirably 290 to 420℃, and more desirably 320

to 380℃. Also, the attenuation value was measured at

50 kFCI. The attenuation value was found to be -0.10

to -0.15 dB/decade when it comes to the recording

20   medium manufactured under temperatures within a range

of between 290℃ and 420℃, supporting that a satisfac-

tory resistance to the thermal decay was maintained.

FIG. 2 is a graph showing the relationship

between the film-forming temperature and the SNRm

25   in respect of a perpendicular recording layer of

Co-16 at%Pt-14 at%Cr-yat%W. Curve 201 included in

the graph covers the case where y is 0, curve 202

included in the graph covers the case where y is 5,
and curve 203 included in the graph covers the case
where y is 10.

As apparent from curve 201, where Cr is added as
a segregating component to the CoPt series magnetic
material, the optimum SNRm was obtained at about 250℃
because Cr exhibits a relatively high segregating
rate. On the other hand, when it comes to the
perpendicular magnetic recording medium including
a perpendicular recording layer containing Cr or W,
a maximal value derived from Cr was caused to appear
at about 250℃ as in FIG. 1 in addition to the maximal
value derived from W, which appeared at about 375℃,
as apparent from curves 202 and 203. Curves 202 and
203 support that, in the case of using a perpendicular
recording layer containing Co, Pt, Cr and W and not
containing Mo, a satisfactory SNRm value can be
obtained at 280 to 450℃, desirably 300 to 425℃, and
more desirably 320 to 410℃. Also, the attenuation
value was measured at 50 kFCI. The attenuation value
was found to be -0.11 to -0.16 dB/decade when it comes
to the recording medium manufactured under tempera-
tures within a range of between 300℃ and 425℃,
supporting that a satisfactory resistance to the
thermal decay was maintained.

FIG. 3 is a graph showing the relationship
between the film-forming temperature and the SNRm

in respect of a perpendicular recording layer of Co-16 at%Pt-14 at%Cr-xat%Mo-yat%W. Curve 301 included in the graph covers the case where each of x and y is 0, curve 202 included in the graph covers the case where each of x and y is 5, and curve 203 included in the graph covers the case where each of x and y is 10.

As apparent from curve 301, where Cr is added as a segregating component to the CoPt series magnetic material, the optimum SNRm was obtained at about 250℃ because Cr exhibits a relatively high segregating rate. On the other hand, when it comes to the perpendicular magnetic recording medium including a perpendicular recording layer containing Co, Pt, Cr, Mo and W, a maximal value derived from Cr was caused to appear at about 250℃ as in FIG. 1 in addition to the maximal value derived from W, which appeared at about 350℃, as apparent from curves 302 and 303. Curves 302 and 303 support that, in the case of using a perpendicular recording layer containing Co, Pt, Cr, Mo and W, a satisfactory SNRm value can be obtained at 280 to 480℃, desirably 300 to 460℃, and more desirably 320 to 420℃. Also, the attenuation value was measured at 50 kFCI. The attenuation value was found to be -0.09 to -0.16 dB/decade when it comes to the recording medium manufactured under temperatures within a range of between 300℃ and 460℃, supporting

that a satisfactory resistance to the thermal decay was maintained.

As apparent from the film-forming temperature range within which a satisfactory SNRm value was obtained in any of FIGS. 1 to 3, the perpendicular magnetic recording medium including a perpendicular magnetic layer containing Co, Pt, Cr and an additional component selected from the group consisting of Mo and W should be formed within a range of between 280℃ and 450℃, desirably between 300℃ and 400℃, and more desirably between 320℃ and 380℃.

According to one embodiment of the present invention, Mo and W are sufficiently diffused and segregated at the crystal grain boundary, if the perpendicular magnetic layer is formed at a high film-forming temperature referred to above so as to make it possible to enhance the effect of magnetically separating the magnetic crystal grains and, thus, to obtain a high SNRm value and a high resistance to the thermal decay.

The present inventors have also looked into a suitable addition amount of Mo and W in an attempt to suppress the disturbance of the crystal orienting properties and to obtain a magnetic crystal grain having a hexagonal close-packed structure.

FIG. 4 is a graph showing the relationship between the Cr content and the SNRm value in respect

of a CoPtCrMo series perpendicular magnetic layer.
Curve 401 shown in the graph covers the case where the
CoPtCrMo series perpendicular magnetic layer contains
16 atomic % of Pt, 5 atomic % of Mo, a varied amount
of Cr, and the balance of Co. Curve 402 shown in
the graph covers the case where the CoPtCrMo series
perpendicular magnetic layer contains 16 atomic % of
Pt, 10 atomic % of Mo, a varied amount of Cr, and the
balance of Co. Further, curve 403 shown in the graph
covers the case where the CoPtCrMo series perpendicu-
lar magnetic layer contains 16 atomic % of Pt,
15 atomic % of Mo, a varied amount of Cr, and the
balance of Co.

    As apparent from the curves 401, 402 and 403,
a satisfactory SNRm value can be obtained in the case
where the perpendicular magnetic layer contains 5 to
20 atomic % of Cr. Also, the attenuation value was
measured at 50 kFCI. The attenuation value was found
to be -0.12 to -0.15 dB/decade when it comes to the
recording medium containing 5 to 20 atomic % of Cr,
supporting that a satisfactory resistance to the
thermal decay was maintained.

    FIG. 5 is a graph showing the relationship
between the Mo content and the SNRm value in respect
of a CoPtCrMo series perpendicular magnetic layer.
Curve 501 shown in the graph covers the case where the
CoPtCrMo series perpendicular magnetic layer contains

16 atomic % of Pt, a varied amount of Mo, and the balance of Co.   Curve 502 shown in the graph covers the case where the CoPtCrMo series perpendicular magnetic layer contains 16 atomic % of Pt, 10 atomic %

5   of Mo, a varied amount of Mo, and the balance of Co. Further, curve 503 shown in the graph covers the case where the CoPtCrMo series perpendicular magnetic layer contains 16 atomic % of Pt, 15 atomic % of Pt, a varied amount of Mo, and the balance of Co.

10   As apparent from the curves 501, 502 and 503, a satisfactory SNRm value can be obtained in the case where the perpendicular magnetic layer contains 5 to 20 atomic % of Mo.   Also, the attenuation value was measured at 50 kFCI.   The attenuation value was found

15   to be -0.12 to -0.14 dB/decade when it comes to the recording medium containing 5 to 20 atomic % of Mo, supporting that a satisfactory resistance to the thermal decay was maintained.

FIG. 6 is a graph showing the relationship

20   between the Mo content and the SNRm value in respect of a CoPtCrMoW series perpendicular magnetic layer. Curve 601 shown in the graph covers the case where the CoPtCrMo series perpendicular magnetic layer contains 16 atomic % of Pt, 14 atomic % of Cr, 5 atomic % of

25   Mo, a varied amount of W, and the balance of Co.

As apparent from the curves 601, a satisfactory SNRm value can be obtained in the case where the

perpendicular magnetic layer contains 5 to 15 atomic %

of W.   Also, the attenuation value was measured at

50 kFCI.   The attenuation value was found to be -0.13

to -0.16 dB/decade when it comes to the recording

5   medium containing 5 to 15 atomic % of W, supporting

that a satisfactory resistance to the thermal decay

was maintained.

It is desirable for the perpendicular recording

layer used in the present invention to contain 5 to

10   25 atomic % of Pt and 50 to 80 atomic % of Co.   The

amounts of these components denote a range within

which the Co-based magnetic crystal grains contained

in the perpendicular magnetic layer form a hexagonal

close-packed (HCP) structure.

15   For forming the perpendicular magnetic layer at

the film-forming temperature employed in the present

invention, it is impossible to use a conventional

substrate having a low heat resistance temperature

of about 250°C such as an aluminosilicate glass,

20   a chemically reinforced glass or a NiP-plated AlMg

substrate.   In the present invention, it is possible

to use suitably a nonmagnetic substrate having a high

heat resistance temperature such as a crystallized

glass substrate, a Si substrate, a C substrate or a Ti

25   substrate.

FIG. 7 is a cross sectional view showing as an

example the construction of the perpendicular magnetic

recording medium of the present invention. As shown
in the drawing, the perpendicular magnetic recording
medium 10 of the present invention comprises a
nonmagnetic substrate 1 and a perpendicular magnetic
5   layer 2 formed on the nonmagnetic substrate 1.

FIG. 8 is a cross sectional view showing as
another example the construction of the perpendicular
magnetic recording medium of the present invention.
As shown in the drawing, the perpendicular magnetic
10   recording medium 20 of the present invention is
substantially equal in construction to the perpen-
dicular magnetic recording medium shown in FIG. 7,
except that an underlayer 3 is interposed between
the nonmagnetic substrate 1 and the perpendicular
15   recording layer 2.

The underlayer 3 is formed of at least one
material selected from the group consisting of Ti, Ru,
Cr, Hf, Co, Pt, B, Cu, Ta, Mo and W, in one embodiment
at least one material selected from the group
20   consisting of Ti, Ru, RuCr, Hf, CoCrPt, CoCrPtB,
CoCrPtRu, CoCrPtCu, CoCrPtTa, CoCrPtMo and CoCrPtW.
In some embodiments, the underlayer should be formed
of at least one material selected from the group
consisting of Co, Cr and Pt. Further, in some
25   embodiments, the underlayer should be formed of at
least one material selected from the group consisting
of Co, Cr and Pt and at least one additional material

selected from the group consisting of B, Ta, Ru and O.

In the present invention, the orienting properties of the perpendicular magnetic film tend to be disturbed by the addition of Mo and/or W. Therefore, it is desirable to form at least one nonmagnetic underlayer having an HCP structure below the perpendicular magnetic film.

FIG. 9 is a cross sectional view showing as another example the construction of the perpendicular magnetic recording medium of the present invention. As shown in the drawing, the perpendicular magnetic recording medium 30 of the present invention is substantially equal in construction to the perpendicular magnetic recording medium shown in FIG. 7, except that an underlayer 4 is of a double layer structure consisting of a first underlayer 5 and a second underlayer 6.

As shown in the drawing, it is possible to use a material similar to the material of the underlayer 3 shown in FIG. 8 for forming the first underlayer 5.

For forming the second underlayer, in one embodiment of the invention it is possible to use at least one material selected from the group consisting of Ni, Nb, Ta, Al, W, Co, C and Ti, in some embodiments at least one material selected from the group consisting of NiNb, NiTa, NiAl, NiW, NiTaW, CoNb, CoW, CoTa, NiTaC, CoTaW, CoTaC, CoTaW and Ti.

In some embodiments, it is possible to use a Ni compound such as NiNb, NiTa, NiAl, NiW, NiTaW and NiTaC for forming the second underlayer. The use of such a Ni compound is advantageous in that high orientation controllability can be obtained with a small film thickness and that the grains of the film formed on the underlayer can have an appropriate grain size.

FIG. 10 is a cross sectional view showing as another example the construction of the perpendicular magnetic recording medium of the present invention. As shown in the drawing, the perpendicular magnetic recording medium 40 of the present invention is substantially equal in construction to the perpendicular magnetic recording medium shown in FIG. 9, except that a soft magnetic backing layer 7 is interposed between the underlayer 4 and the nonmagnetic substrate 1.

Also, it is possible to form a hard magnetic layer (not shown) between the soft magnetic backing layer 7 and the nonmagnetic substrate 1. In the manufacturing process of the perpendicular magnetic recording medium, layers of, for example, CoCrPt and CoZrNb are formed in the order mentioned on a nonmagnetic substrate. It is possible to prevent the generation of a domain wall by applying a magnetic field to the hard magnetic layer in a radial direction

after formation of the CoCrPt and CoZrNb layers so as to apply a bias magnetic field to the soft magnetic layer.

It is possible to form an underlayer made of, for example, Cr, V or NiAl between the hard magnetic layer and the nonmagnetic substrate 1.

The soft magnetic backing layer can be formed of a soft magnetic material having a high permeability including, for example, CoZrNb, FeTaC, FeZrN, an FeSi alloy, an FeAl alloy, an FeNi alloy such as permalloy, an FeCo series alloy such as Permendur, an FeCoNi alloy such as Perminbar, a MgZn series ferrite, a MgMn series ferrite, FeAlGa, FeCuNbSiB, FeGaGe, FeGeSi, FeNiPb, FeRuGaSi, FeSiB, FeSiC, FeZrB, FeZrBCu, CoFeSiB, CoTi and CoZrTa.

A so-called "double-layered perpendicular medium" having a perpendicular magnetic film on a soft magnetic layer is formed by forming a soft magnetic layer having a high permeability. In the double-layered perpendicular medium, the soft magnetic layer plays a part of the role of the magnetic head in which the recording magnetic field generated from the magnetic head for magnetizing the perpendicular magnetic film runs in the horizontal direction, so as to be brought back toward the magnetic head. As a result, it is possible for the soft magnetic layer to improve the recording-reproducing efficiency.

Also, the hard magnetic layer is formed of, for example, CoSm, CoPt, CoCrPt, CoCrPtB and CoCrPtCu.

FIG. 11 is a cross sectional view showing as another example the construction of the perpendicular magnetic recording medium of the present invention. As shown in the drawing, the perpendicular magnetic recording medium 50 of the present invention is substantially equal in construction to the perpendicular magnetic recording medium shown in FIG. 7, except that another perpendicular recording layer 8 is interposed between the underlayer 3 and the perpendicular recording layer 2.

The "another perpendicular recording film" referred to above is formed of, for example, CoPt, CoCrPt, CoCrO, CoPtO, CoPtCrO, CoCrPtB, CoCrPtTa, CoCrPtW, CoCrPtMo, CoCrPtCu, CoCrPtRu, CoCrPtWC, CoCrPtRuC, CoCrPtCuB, CoCrPtWB, CoCrPtTaCu, CoCrPtTaW, $CoPt-SiO_2$ and CoPtSiO.

Incidentally, each layer included in the perpendicular magnetic recording medium shown in any of FIGS. 7 to 11 can be combined appropriately.

It is possible to form a protective layer made of, for example, C on the surface of the perpendicular magnetic recording medium used in the present invention.

Further, it is possible to form a lubricating layer on the surface of the perpendicular magnetic

layer or the surface of the protective layer used in the present invention by, for example, a dipping method.

FIG. 12 is a partial cutaway, exemplifying the construction of a magnetic recording-reproducing apparatus of the present invention.

As shown in the drawing, a magnetic disk 121 of a rigid structure used in the present invention for recording information is mounted to a spindle 122, and is rotated at a prescribed constant rotating speed by a spindle motor (not shown). A slider 123 having, for example, a mono-magnetic pole type recording head and an MR head for reproducing the recorded information are mounted to the tip of a suspension 124 made of a thin plate-like leaf spring. The suspension 124 is connected to one edge side of an arm 125 having, for example, a bobbin portion for holding a driving coil (not shown).

A voice coil motor 126, which is a kind of linear motor, is mounted to the other edge side of the arm 125. The voice coil motor 126 includes a driving coil (not shown) wound about the bobbin portion of the arm 125 and a magnetic circuit consisting of a permanent magnet and a counter yoke arranged to face each other in a manner to have the driving coil held therebetween.

The arm 125 is held by ball bearings (not shown)

arranged at upper and lower portions of a stationary
arm 127 so as to be swung and rocked by the voice coil
motor 126. To be more specific, the position of the
slider 123 on the magnetic disk 121 is controlled by

5   the voice coil motor 126. Incidentally, a reference
numeral 128 shown in the drawing denotes a lid body.

Examples:

The present invention will now be described in
detail with reference to some Examples of the present

10   invention.

Example 1:

Prepared was a nonmagnetic substrate consisting
of a Si substrate for a 2.5 inch magnetic disk.
The nonmagnetic Si substrate was put in a vacuum

15   chamber having a degree of vacuum of 1×10^{-5} Pa, and
a DC magnetron sputtering was performed within an Ar
gas atmosphere having a gas pressure of 0.6 Pa while
heating the substrate temperature to 350°C. In the
first step, the nonmagnetic substrate was arranged

20   to face the target, thereby forming a Cr film in
a thickness of 40 nm under the condition of a DC
sputtering power of $2.4W/cm^2$ as a nonmagnetic backing
layer.

In the next step, a CoCrPt hard magnetic layer

25   was formed in a thickness of 25 mm on the nonmagnetic
backing layer, followed by forming a CoZrNb soft
magnetic backing layer in a thickness of 200 nm on the

CoCrPt hard magnetic layer.

Then, a second underlayer having a thickness of 5 nm on the CoZrNb soft magnetic backing layer is formed, thereby forming a Ni-30at%Nb film under the condition of a DC sputtering power of $1.4W/cm^2$.

In the next step, a first underlayer having a thickness of 15 nm on the NiNb film is formed, thereby forming a nonmagnetic HCP structured Ru film under the condition of a DC sputtering power of $2.4W/cm^2$.

Further, a CoPtCrMo perpendicular magnetic film was formed in a thickness of 30 nm on the nonmagnetic Ru underlayer by using a target made of Co-16at%Pt-14at%Cr-5at%Mo.

Finally, a C protective layer was formed in a thickness of 7 nm.

The substrate having the various films consecutively formed thereon within the vacuum container was removed to an air atmosphere, followed by forming a perfluoropolyether (PFPE) series lubricating layer in a thickness of 1.5 nm on the C protective layer by a dipping method so as to obtain a perpendicular magnetic recording medium 60.

FIG. 13 schematically shows the construction of the perpendicular magnetic recording medium 60 thus obtained. As shown in the drawing, the perpendicular magnetic recording medium 60 comprises a Cr nonmagnetic layer 10, a CoCrPt hard magnetic layer 9,

a CoZrNb soft magnetic layer 7, an underlayer 4

consisting of a NiNb second underlayer 6 and a Ru

first underlayer 5, a CoPtCrMo perpendicular magnetic

film 2, a C protective layer 11, and a lubricating

5   layer, which are successively laminated one upon the

other in the order mentioned on a nonmagnetic

substrate 1.

The local distribution of the element concentra-

tion in the perpendicular magnetic layer included in

10   the perpendicular magnetic recording medium thus

obtained was examined by using an energy dispersion

type X-ray spectroscopic apparatus (TEM-EDX).

The perpendicular magnetic layer was found to include

Co-based magnetic crystal grains containing Co as a

15   main component and crystal grain boundaries containing

Mo and Cr as main components and positioned to

surround the Co-based magnetic crystal grains.

A magnetic field of 1185 kA/m was applied

radially outward to the circular substrate included in

20   the perpendicular magnetic recording medium 60 thus

obtained by using a magnetizing apparatus equipped

with an electromagnet so as to magnetize radially

inward the hard magnetic layer. The evaluation of

the recording-reproducing characteristics utilizing

25   the magnetoresistance effect was performed by using

a mono-magnetic head having a recording truck width of

0.3 μm and a reproducing truck width of 0.2 μm in

respect of the magnetized perpendicular magnetic recording medium. The SNRm (S denoting the low frequency signal, and N denoting the noise of 400 kFCI) was found to be 23.0 dB, which was

5   satisfactory. Also, the attenuation value at 50 kFCI, which provides an index of the thermal decay, was found to be -0.12 dB/decade, which was also satisfactory.

Comparative Example 1:

10   For comparison, a perpendicular magnetic recording medium was prepared as in Example 1, except that CoCrPt layer was formed in a thickness of 30 nm by using a Co-19at%Cr-16at%Pt target on the nonmagnetic substrate in place of the CoPtCrMo

15   perpendicular magnetic film. The local distribution of the element concentration was examined by using a TEM-EDX in respect of the perpendicular magnetic recording medium thus obtained. The perpendicular magnetic recording medium was found to include

20   Co-based magnetic crystal grains containing Co as a main component and crystal grain boundaries containing Cr as a main component and positioned to surround the Co-based magnetic crystal grains. Also, the recording-reproducing characteristics were

25   evaluated as in Example 1, with the result that the SNRm was found to be 20.7 dB. Also, the attenuation value at 50 kFCI was found to be -0.20 dB/decade,

which clearly indicated that the resistance to the thermal decay was poor.

Example 2:

A perpendicular magnetic recording medium was obtained as in Example 1, except that a nonmagnetic CoCrPt film was formed in a thickness of 20 nm as the first underlayer under the condition of a DC sputtering power of 2.4W/cm^2 against a Co-37at%Cr-8at%Pt target having a hexagonal close-packed structure.

The local distribution of the element concentration was examined in respect of the perpendicular magnetic layer included in the perpendicular magnetic recording medium thus obtained. The perpendicular magnetic layer was found to have been constructed to include Co-base magnetic crystal grains containing Co as a main component and crystal grain boundaries containing Mo and Cr as main components and positioned to surround each of the Co-based magnetic crystal grains.

Also, a rocking curve measurement was performed to the Co (00.2) peak by using an X-ray diffraction apparatus in respect of the perpendicular magnetic recording medium. The half value width of the peak was found to be 7°, which was satisfactory. This supports that the orienting properties of Co were satisfactory. Also, the recording-reproducing

characteristics were evaluated as in Example 1.
The SNRm value was found to be 23.5 dB, which was
satisfactory. Also, the attenuation value at 50 kFCI
was found to be -0.11 dB/decade, supporting that the
5   resistance to the thermal decay was satisfactory.

Comparative Example 2:

A conventional perpendicular magnetic recording
medium was obtained as in Example 1, except that a Pt
film was formed on a nonmagnetic substrate in a
10   thickness of 30 nm by using a Pt body having a face
centered cubic (FCC) structure as a target so as to
provide the first underlayer.

The local distribution of the element concentra-
tion was examined in respect of the perpendicular
15   magnetic layer included in the perpendicular magnetic
recording medium thus obtained. The perpendicular
magnetic layer was found to have been constructed to
include Co-base magnetic crystal grains containing Co
as a main component and crystal grain boundaries
20   containing Cr as a main component and positioned to
surround each of the Co-based magnetic crystal grains.
However, the grain boundary was not clear in the
perpendicular magnetic layer.

Also, a rocking curve measurement was applied to
25   the Co (00.2) peak by using an X-ray diffraction
apparatus in respect of the perpendicular magnetic
recording medium. The half value width of the peak

was found to be 11°. In other words, the crystal orienting properties of the Co-based magnetic crystal grains were poor, compared with the perpendicular magnetic recording medium prepared in Example 2.

5   Also, the recording-reproducing characteristics were evaluated. The SNRm value was found to be 19.2 dB. Also, the attenuation value at 50 kFCI was found to be -0.25 dB/decade, indicating that the resistance to the thermal decay was not satisfactory.

10   Example 3:

A perpendicular magnetic recording medium was obtained as in Example 1, except that a nonmagnetic CoCrPtTa film was formed in a thickness of 20 nm as the first underlayer in place of the Ru film under the

15   condition of a DC sputtering power of $2.4W/cm^2$ against a Co-37at%Cr-8at%Pt-3at%Ta target.

The local distribution of the element concentration was examined in respect of the perpendicular magnetic layer included in the perpendicular magnetic

20   recording medium thus obtained. The perpendicular magnetic layer was found to have been constructed to include Co-base magnetic crystal grains containing Co as a main component and crystal grain boundaries containing Mo and Cr as main components and positioned

25   to surround each of the Co-based magnetic crystal grains.

Also, a rocking curve measurement was applied to

the perpendicular magnetic recording medium thus
obtained as in Example 2. The half value width of
the peak was found to be 5°. Also, the attenuation
value at 50 kFCI was found to be -0.10 dB/decade.

5   Also, a perpendicular magnetic recording medium
was prepared similarly, except that the first
underlayer was formed by adding each of Ru, B and O in
place of Ta. It was possible to obtain the effect of
improving the SNRm value without deteriorating the

10   crystal orienting properties of the Co-based magnetic
crystal grains and the resistance to the thermal
decay.

        Example 4:

        A perpendicular magnetic recording medium ·

15   was obtained as in Example 1, except, after
formation of the first underlayer, a CoCrPt magnetic
film was formed in a thickness of .15 nm by using a
Co-19at%Cr-16at%Pt body used as a target, followed
by forming in a thickness of 15 nm a CoPtCrMo

20   perpendicular magnetic layer similar to that in
Example 1 on the CoCrPt magnetic layer.

        The local distribution of the element concentra-
tion was examined in respect of the perpendicular
magnetic layer included in the perpendicular magnetic

25   recording medium thus obtained by utilizing a TEM-EDX.
The perpendicular magnetic layer was found to have
been constructed to include Co-based magnetic crystal

grains containing Co as a main component and crystal grain boundaries containing Mo and Cr as main components and positioned to surround each of the Co-based magnetic crystal grains.

Also, the recording-reproducing characteristics were evaluated in respect of the perpendicular magnetic recording medium thus obtained. The SNRm value was found to be 23.8 dB, which was satisfactory. Also, the attenuation value at 50 kFCI was found to be -0.11 dB/decade, supporting that the resistance to the thermal decay was satisfactory. Also, the rocking curve measurement was performed to the Co (00.2) peak by using an X-ray diffraction apparatus. The half width value of the peak was found to be 5°.

Example 5:

A perpendicular magnetic recording medium was manufactured as in Example 1, except that the. nonmagnetic Cr layer, the CoCrPt hard magnetic layer and the CoZrNb soft magnetic backing layer were not formed. FIG. 14 is a cross sectional view showing the construction of the perpendicular magnetic recording medium 70 thus obtained. As shown in the drawing, the perpendicular magnetic recording medium 70 was constructed to include the underlayer 4 consisting of the NiNb second underlayer 6 and the first underlayer 5 made of Ru, the CoPtCrMo perpendicular magnetic film 2, the C protective layer 11, and a lubricating layer

(not shown), which are laminated one upon the other on the nonmagnetic substrate 1.

The local distribution of the element concentration was examined in respect of the perpendicular magnetic layer included in the perpendicular magnetic recording medium thus obtained by utilizing a TEM-EDX. The perpendicular magnetic layer was found to have been constructed to include Co-based magnetic crystal grains containing Co as a main component and crystal grain boundaries containing Mo and Cr as main components and positioned to surround each of the Co-based magnetic crystal grains.

Also, the recording-reproducing characteristics were evaluated as in Example 1 in respect of the perpendicular magnetic recording medium thus obtained. The SNRm value was found to be 22.1 dB, which was satisfactory. Also, the attenuation value at 50 kFCI was found to be -0.14 dB/decade, supporting that the resistance to the thermal decay was satisfactory.

Comparative Example 3:

A perpendicular magnetic recording medium was manufactured as in Example 1, except that a CoCrPt layer was formed in a thickness of 30 nm by using a Co-19at%Cr-16at%Pt target in place of the CoPtCrMo perpendicular magnetic film.

The local distribution of the element concentration was examined in respect of the perpendicular

magnetic layer included in the perpendicular magnetic recording medium thus obtained by utilizing a TEM-EDX. The perpendicular magnetic layer was found to have been constructed to include Co-based magnetic crystal

5   grains containing Co as a main component and crystal grain boundaries containing Cr as a main component and positioned to surround each of the Co-based magnetic crystal grains.

Also, the recording-reproducing characteristics

10   were evaluated as in Example 1. The SNRm value was found to be 17.5 dB, which was somewhat unsatis- factory. Also, the attenuation value at 50 kFCI was found to be -0.22 dB/decade, supporting that the resistance to the thermal decay was also

15   unsatisfactory.

Example 6:

A perpendicular magnetic recording medium was manufactured as in Example 1, except that a perpen- dicular magnetic film was formed in a thickness of

20   30 nm as a perpendicular magnetic layer under the condition of a DC sputtering power of $2.4W/cm^2$ using a Co-16at%Pt-15at%Mo body.

The local distribution of the element concentra- tion was examined in respect of the perpendicular

25   magnetic layer included in the perpendicular magnetic recording medium thus obtained. The perpendicular magnetic layer was found to have been constructed to

include Co-based magnetic crystal grains containing Co as a main component and crystal grain boundaries containing Mo as a main component and positioned to surround each of the Co-based magnetic crystal grains.

Also, the rocking curve measurement was performed to the Co (00.2) peak by using an X-ray diffraction apparatus in respect of the perpendicular magnetic recording medium thus obtained. The half width value of the peak was found to be 9°, supporting that the crystal orienting properties of Co were satisfactory. Further, the recording-reproducing characteristics were evaluated as in Example 1. The SNRm value was found to be 23.6 dB, which was satisfactory. Also, the attenuation value at 50 kFCI was found to be -0.12 dB/decade, supporting that the resistance to the thermal decay was satisfactory.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the present invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.